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Bessho et al.

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[54] **METHOD AND APPARATUS FOR CONTINUOUSLY EXCAVATING SHAFT AND TUNNEL**

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[51] **Int. Cl.**[5] **F21D 9/06**
[52] **U.S. Cl.** **405/141**; 299/31; 405/138

[58] **Field of Search** 405/141, 138, 133, 143; 299/31, 33; 175/53, 61, 79

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Primary Examiner—Dennis L. Taylor

[57] **ABSTRACT**

A shield excavator excavates a shaft. Then, the excavator is caused to swing to change its posture and excavate a tunnel. Thus, the shaft and the tunnel is continuously excavated by the single machine.

8 Claims, 15 Drawing Sheets

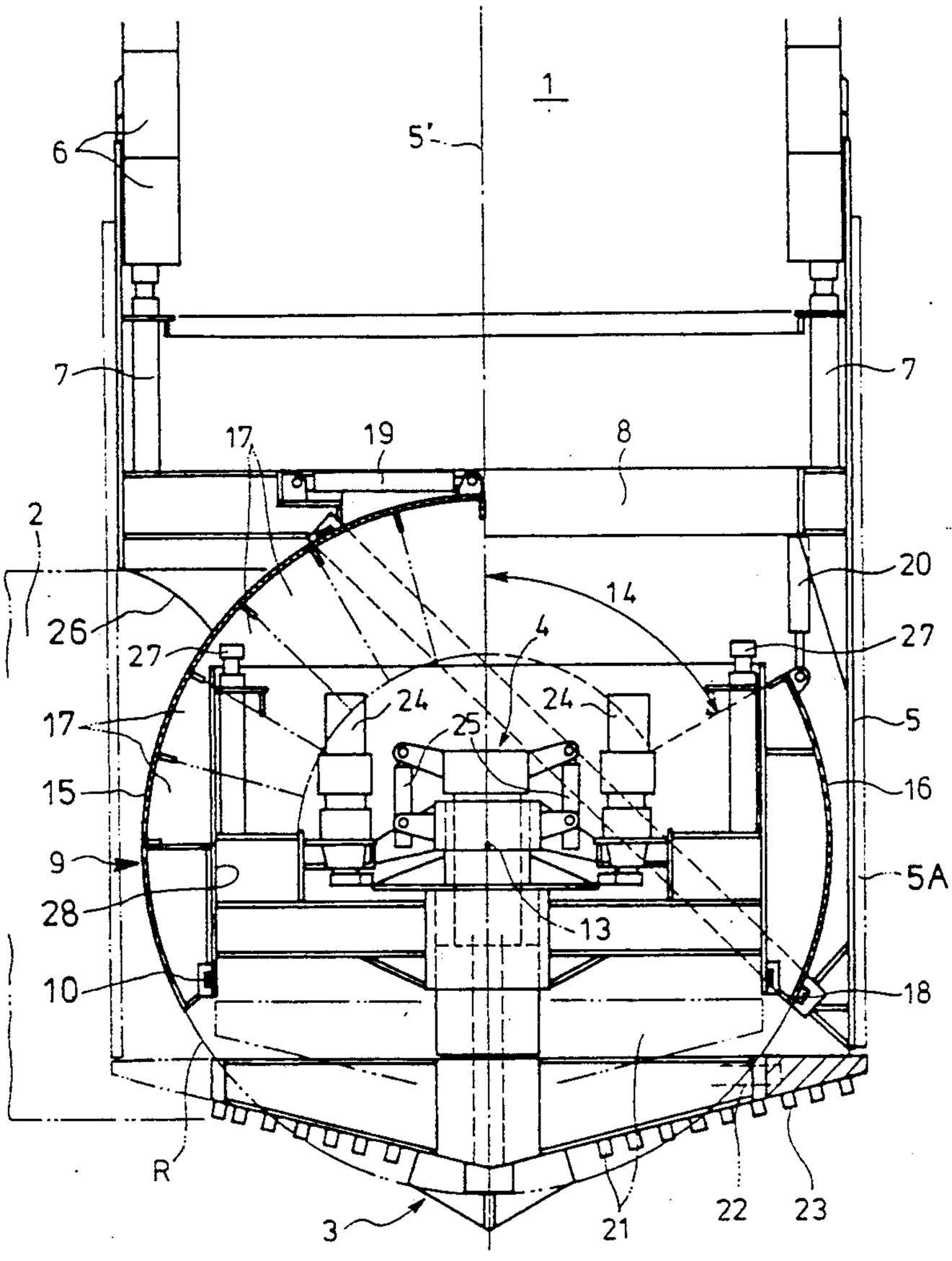

Fig.1

PRIOR ART

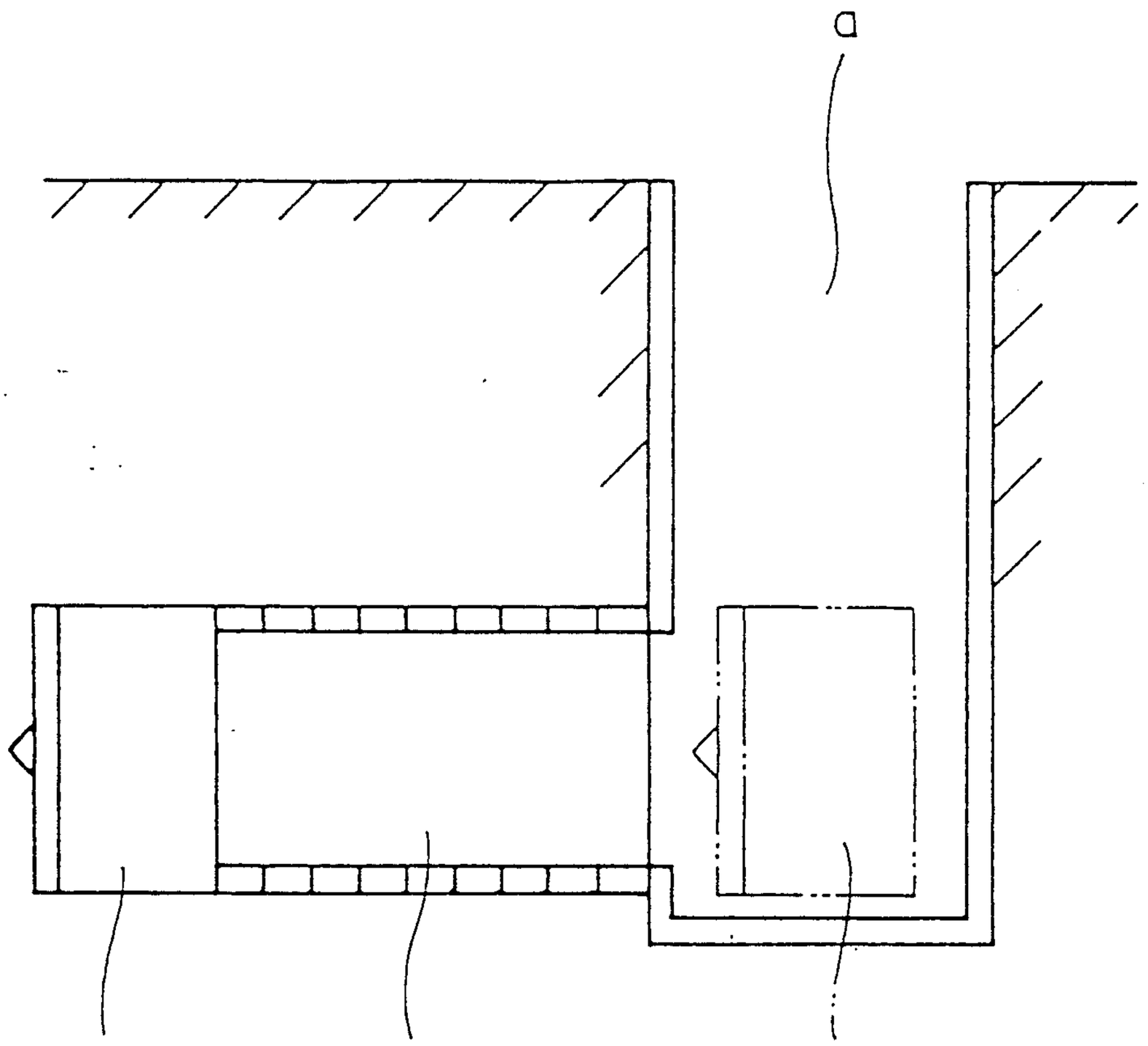

Fig. 2

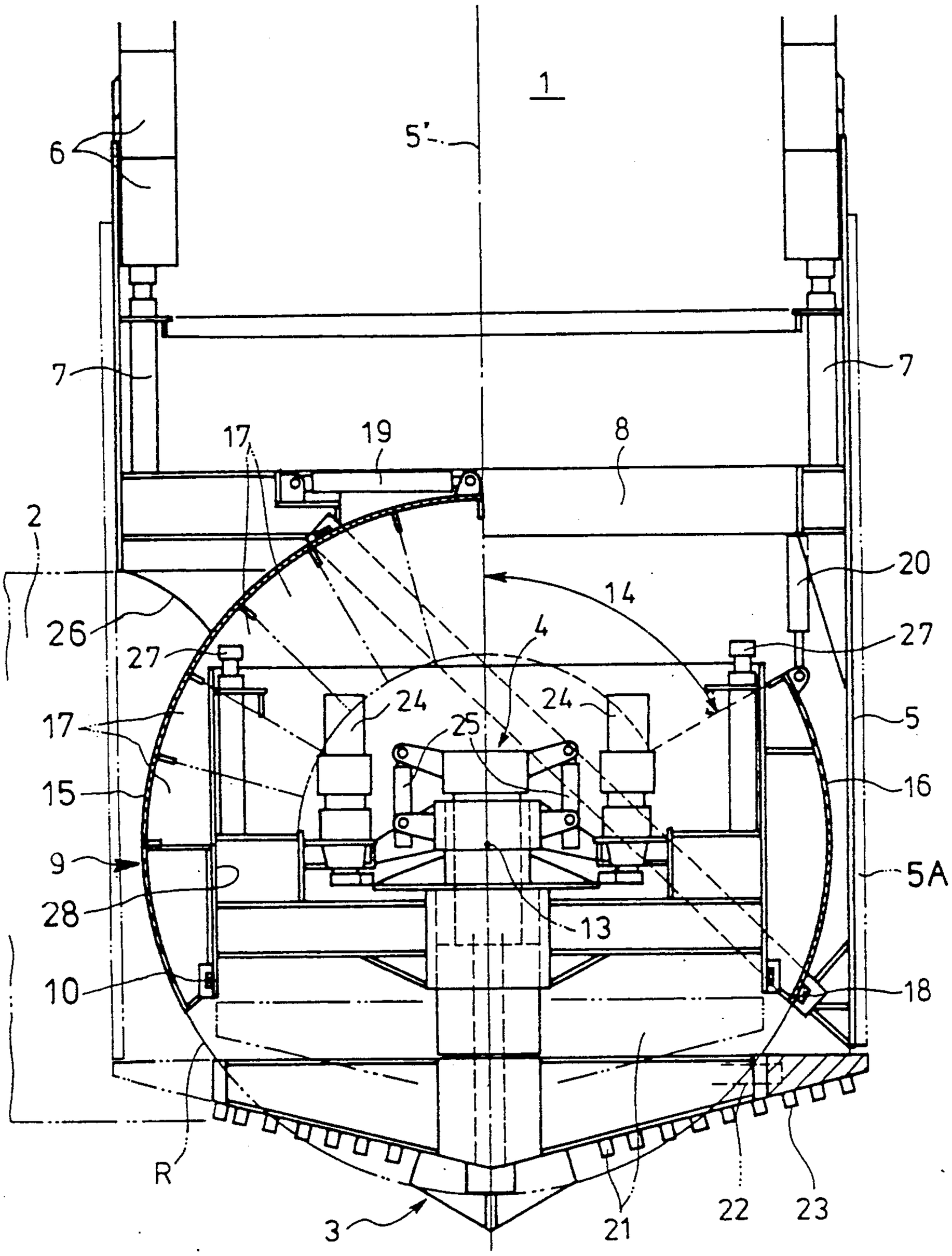
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Fig. 3

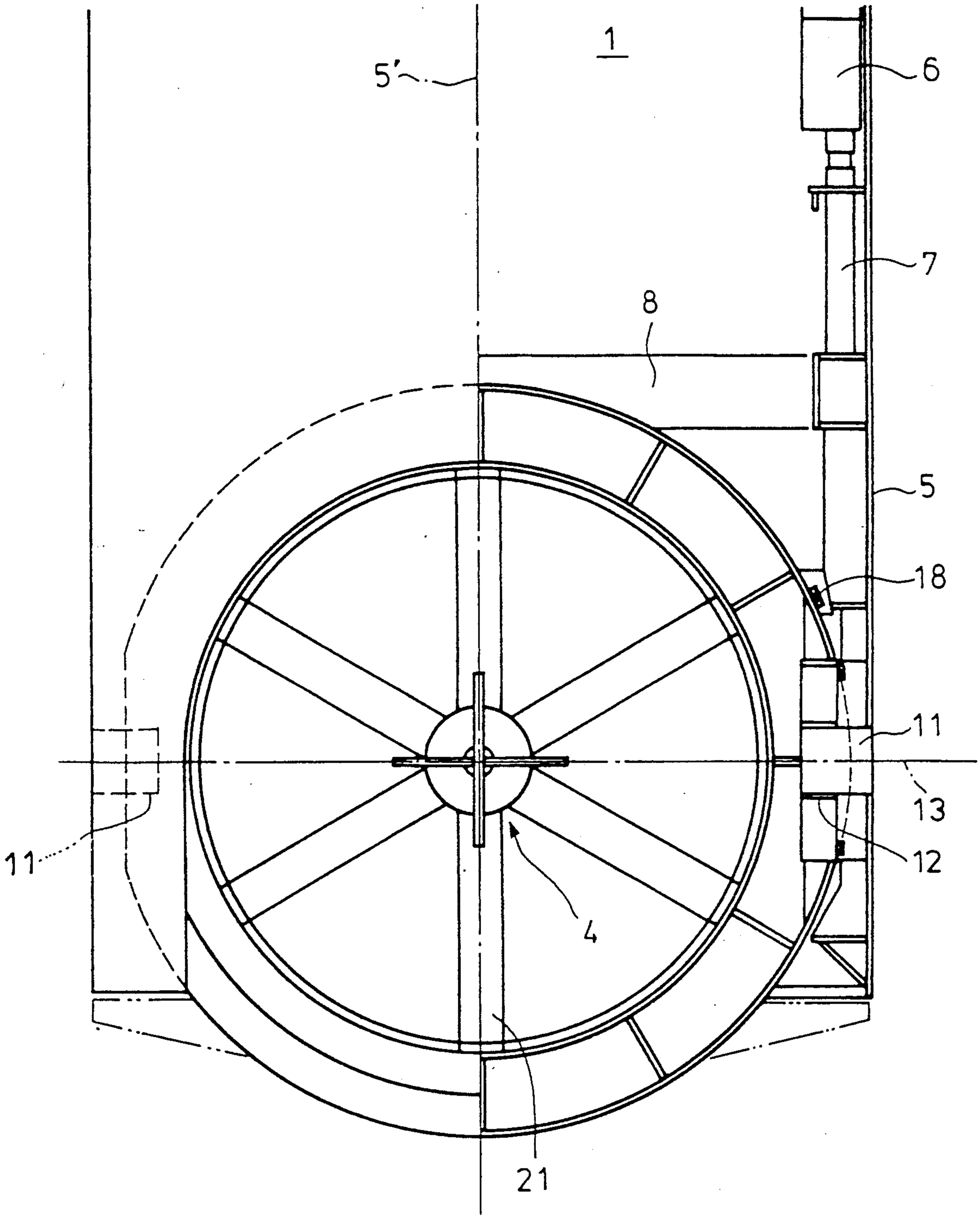

Fig.4

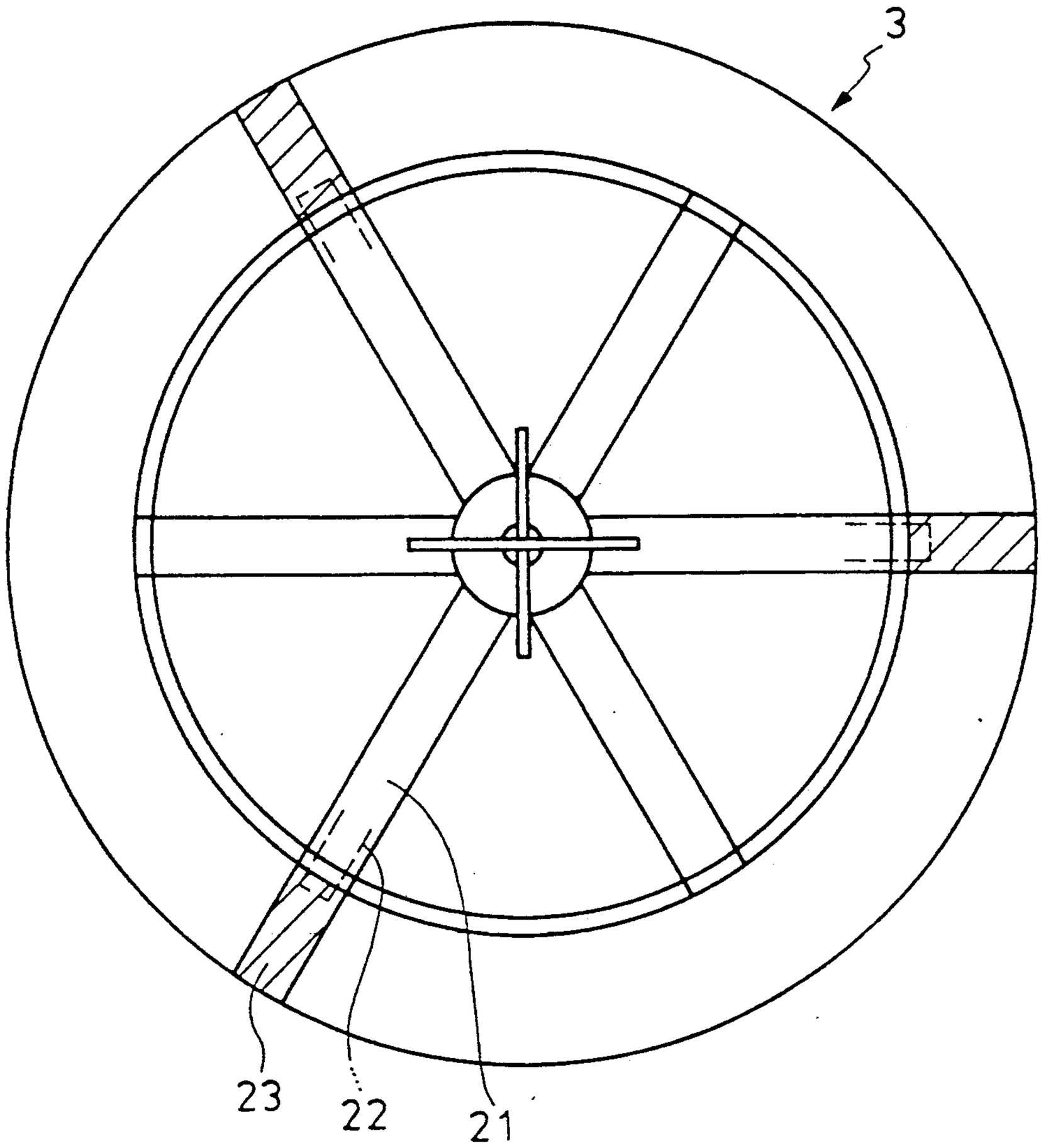

Fig. 5

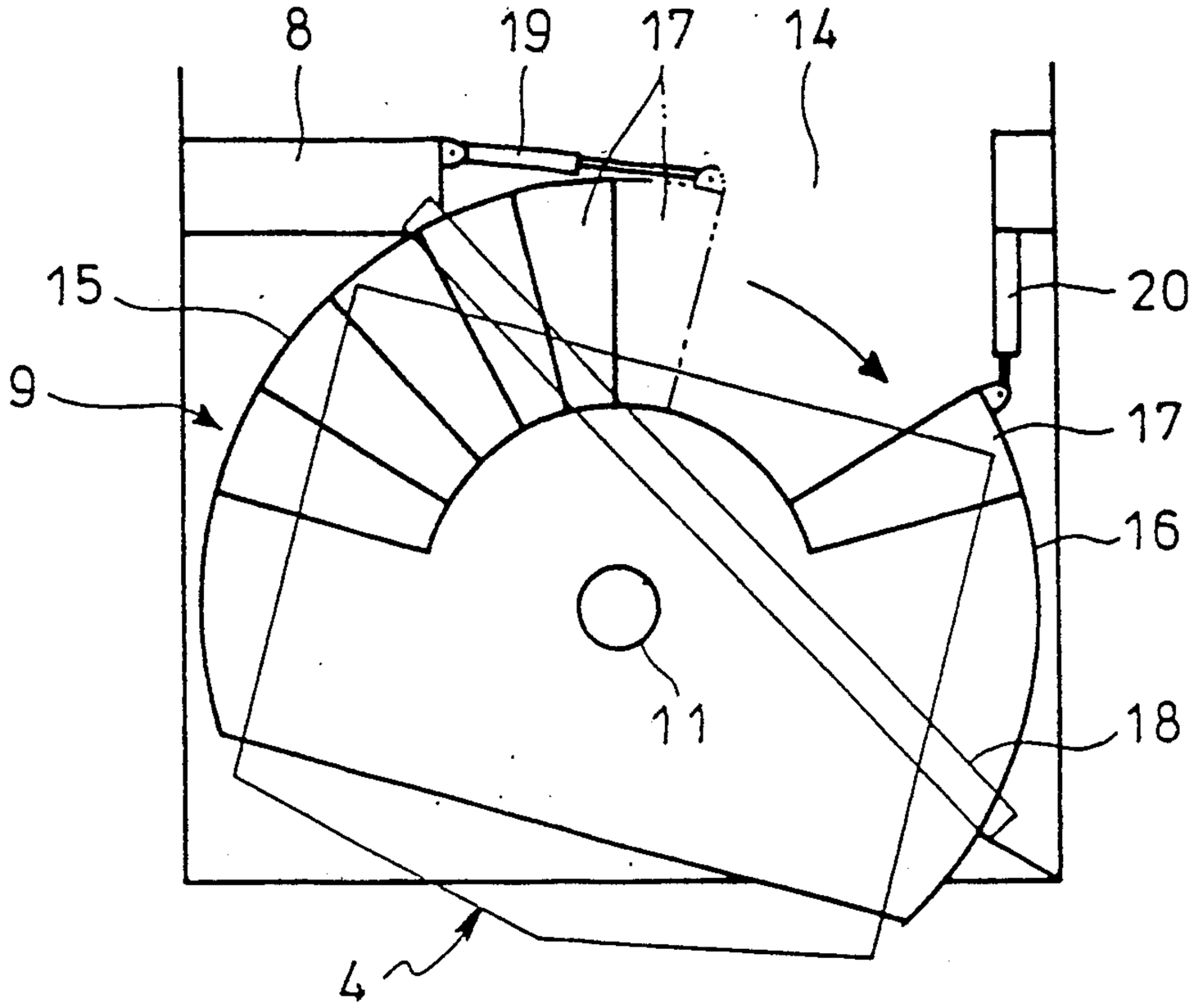

Fig. 6

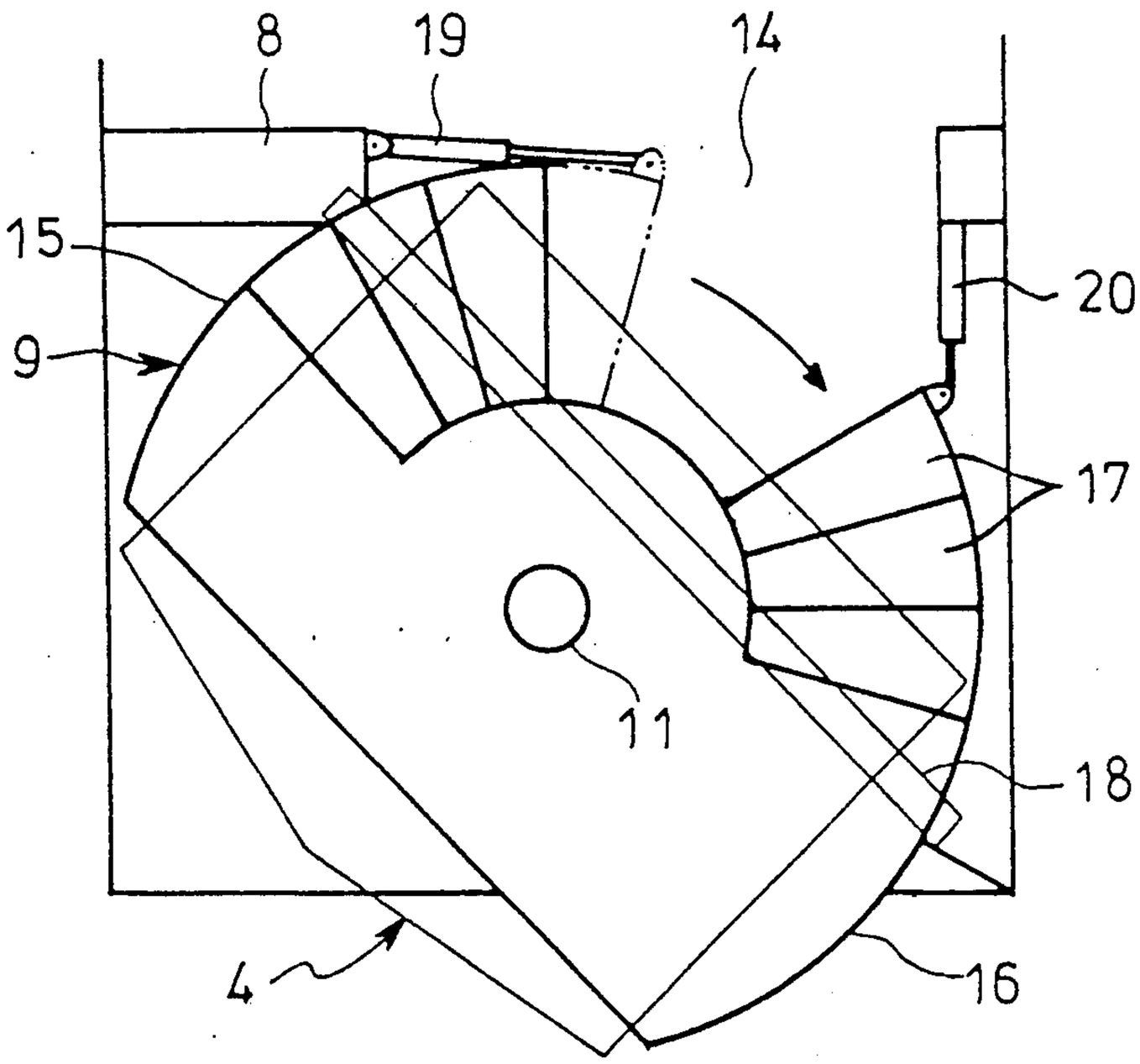

Fig.7

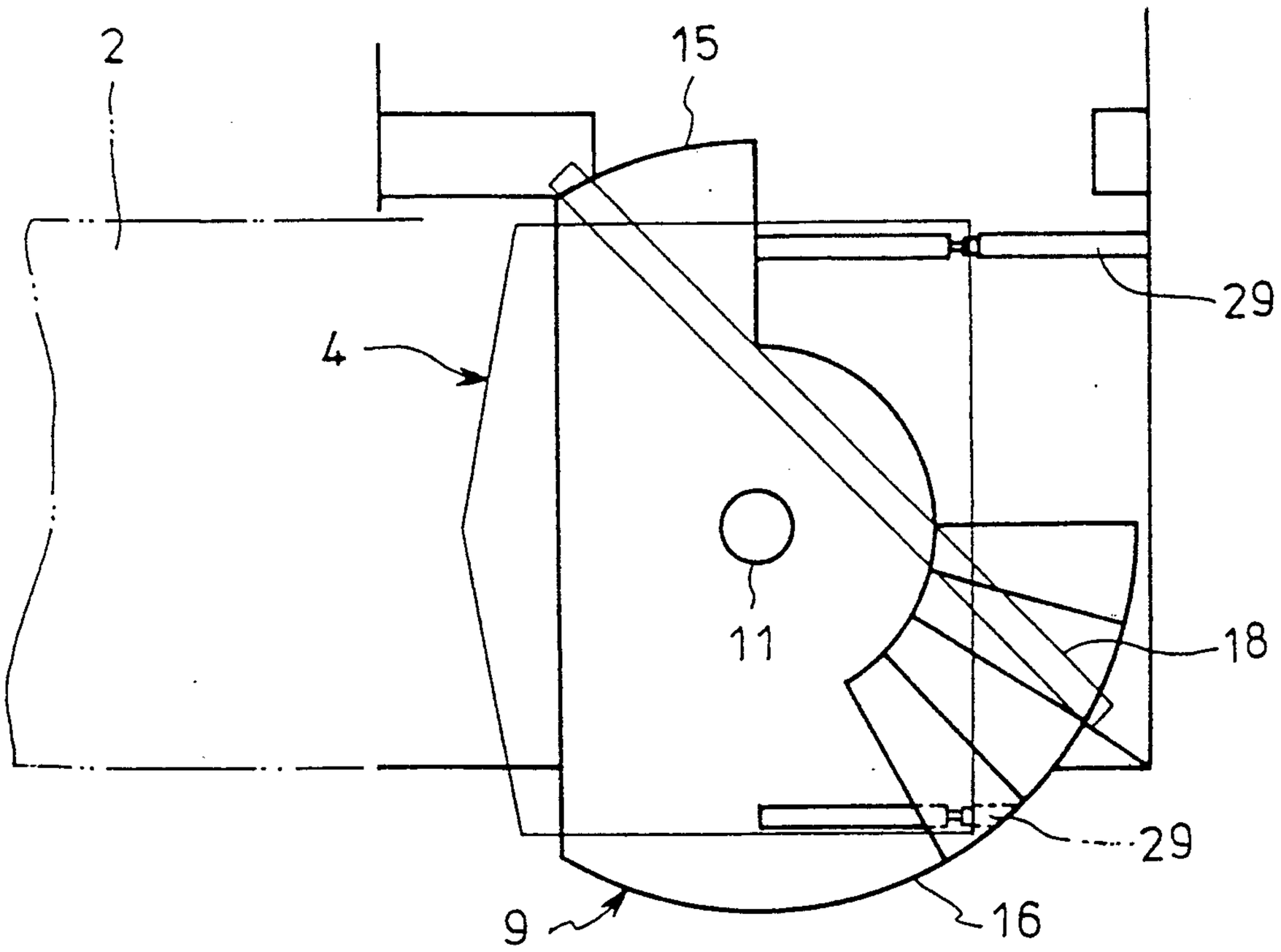

Fig. 8

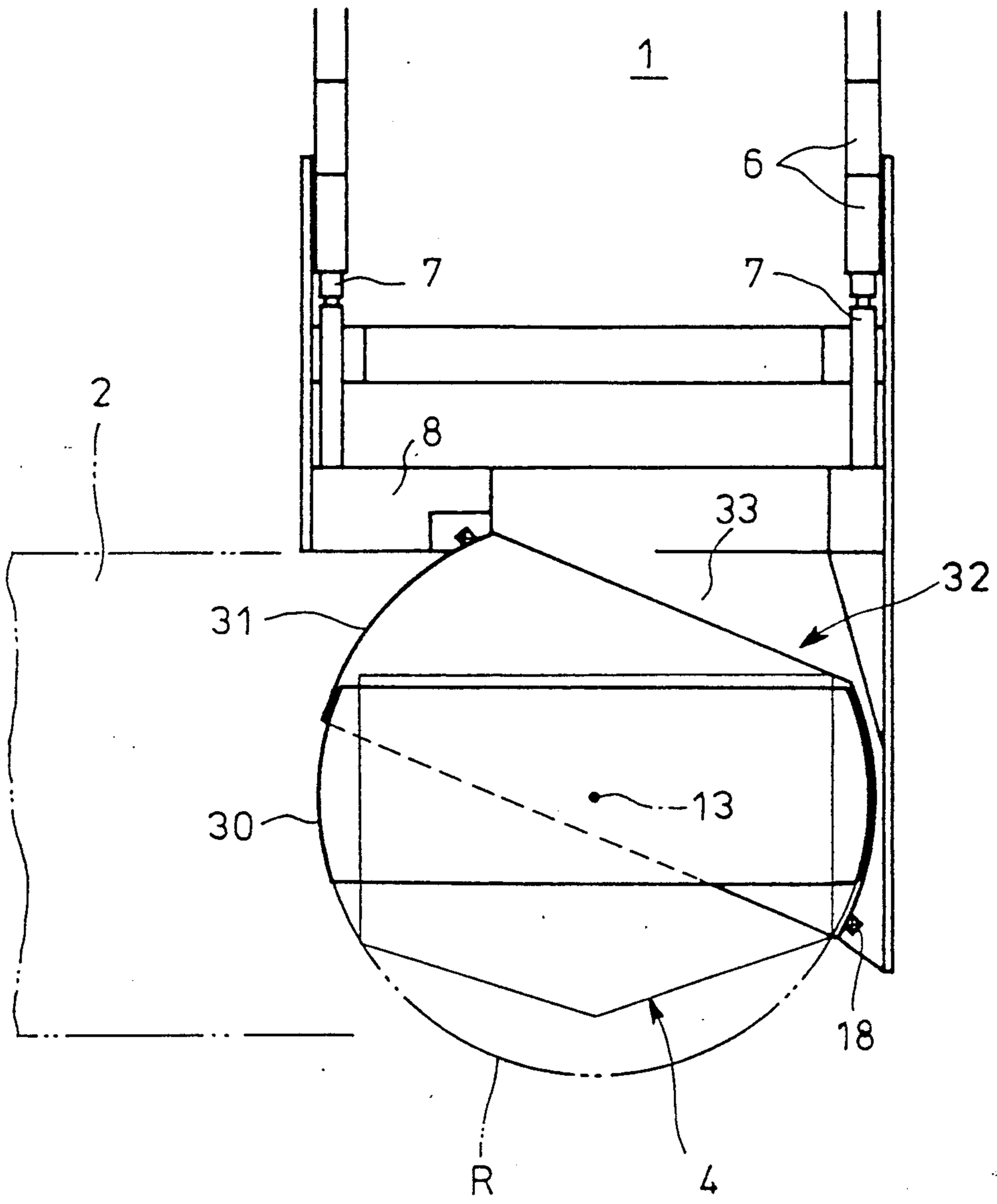

Fig. 9

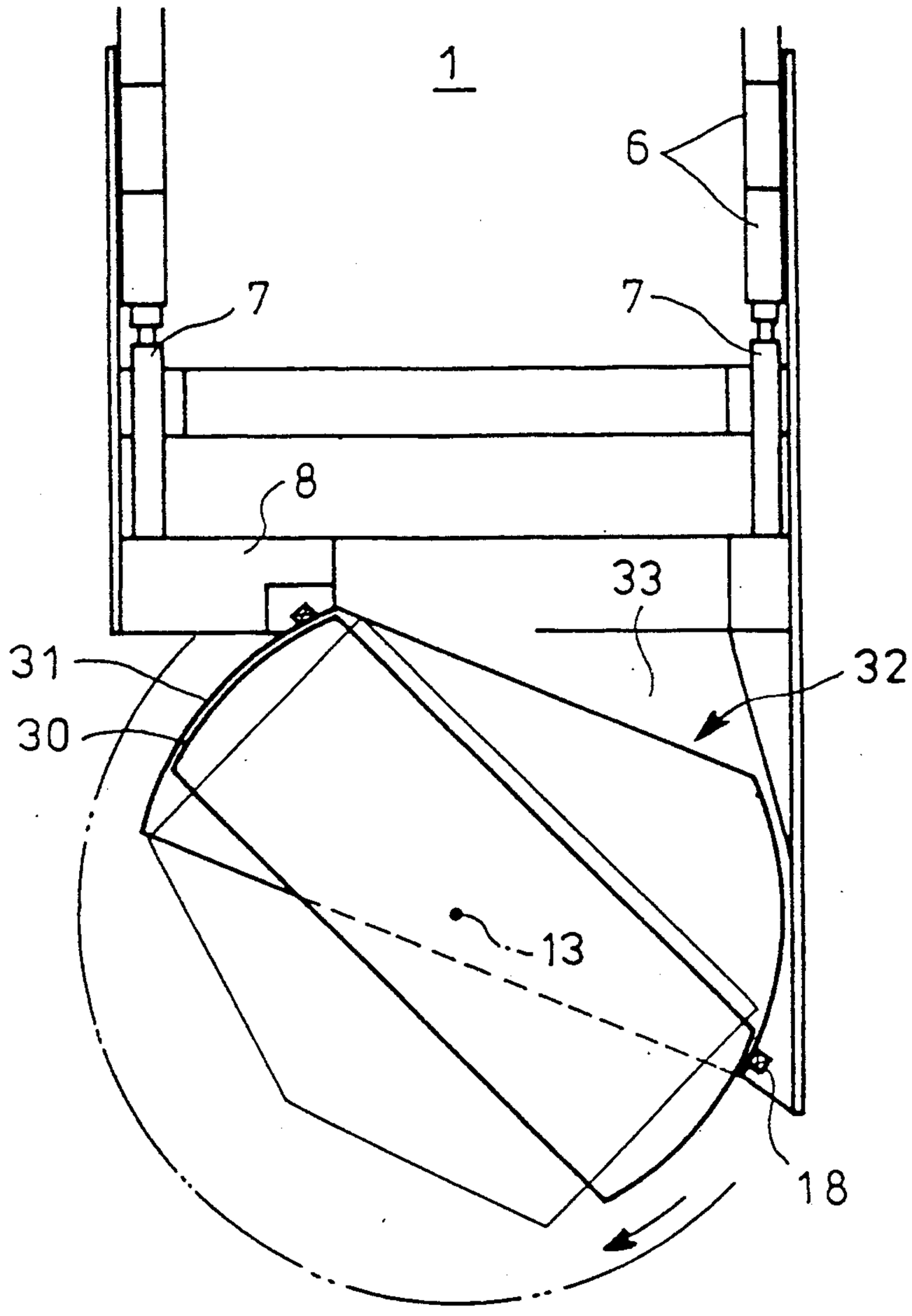

Fig.10

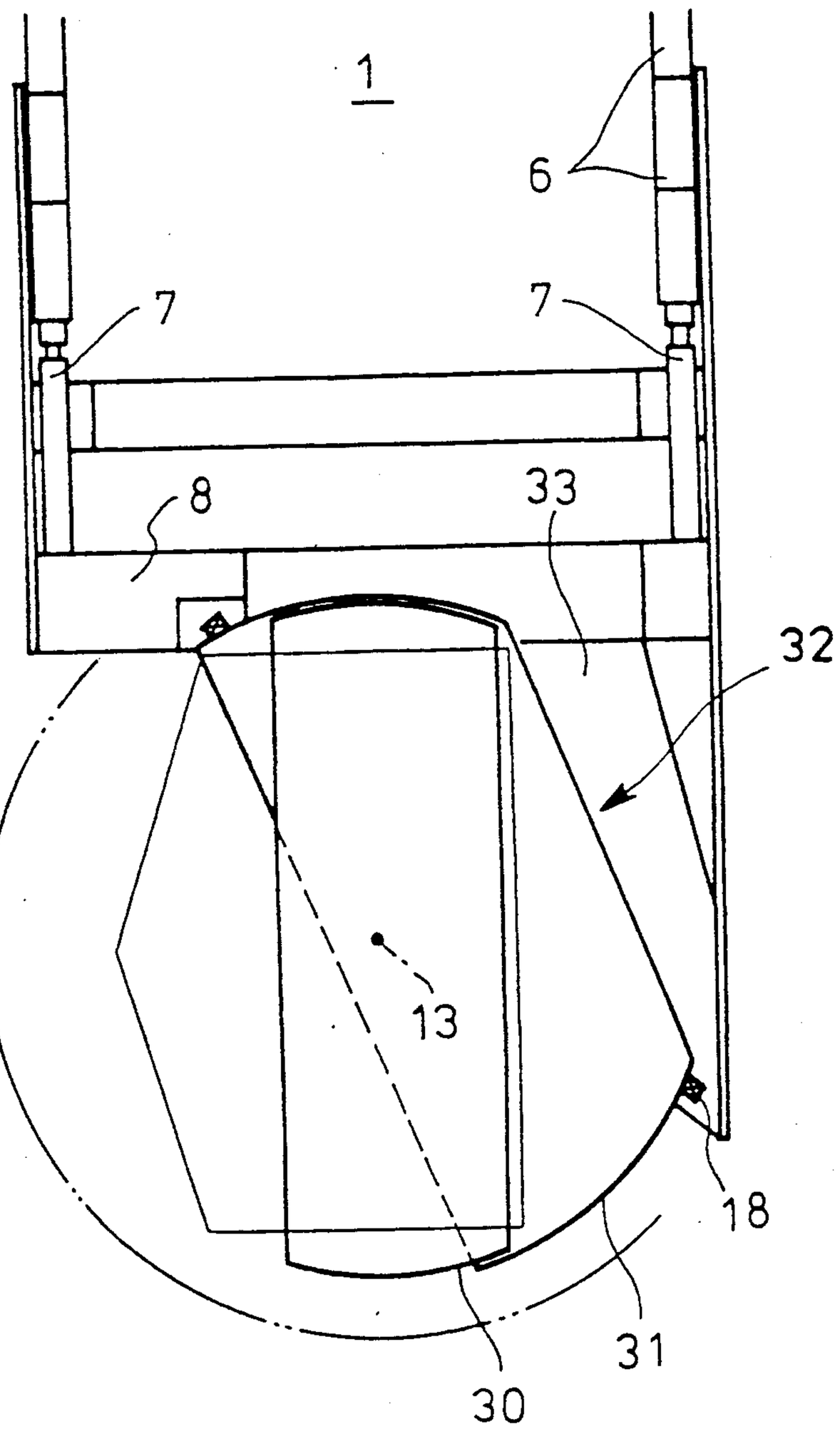

Fig.11

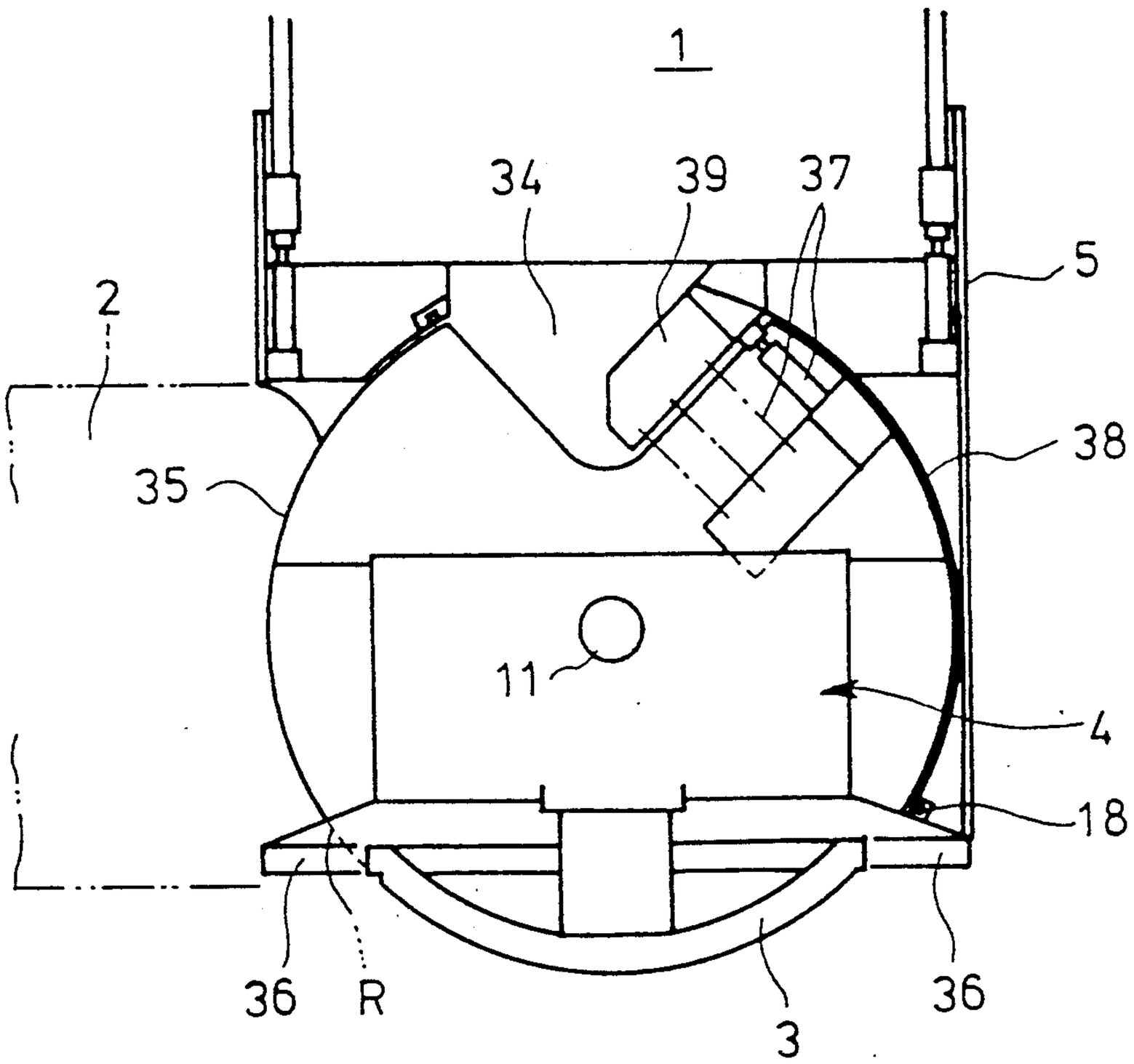

Fig. 12

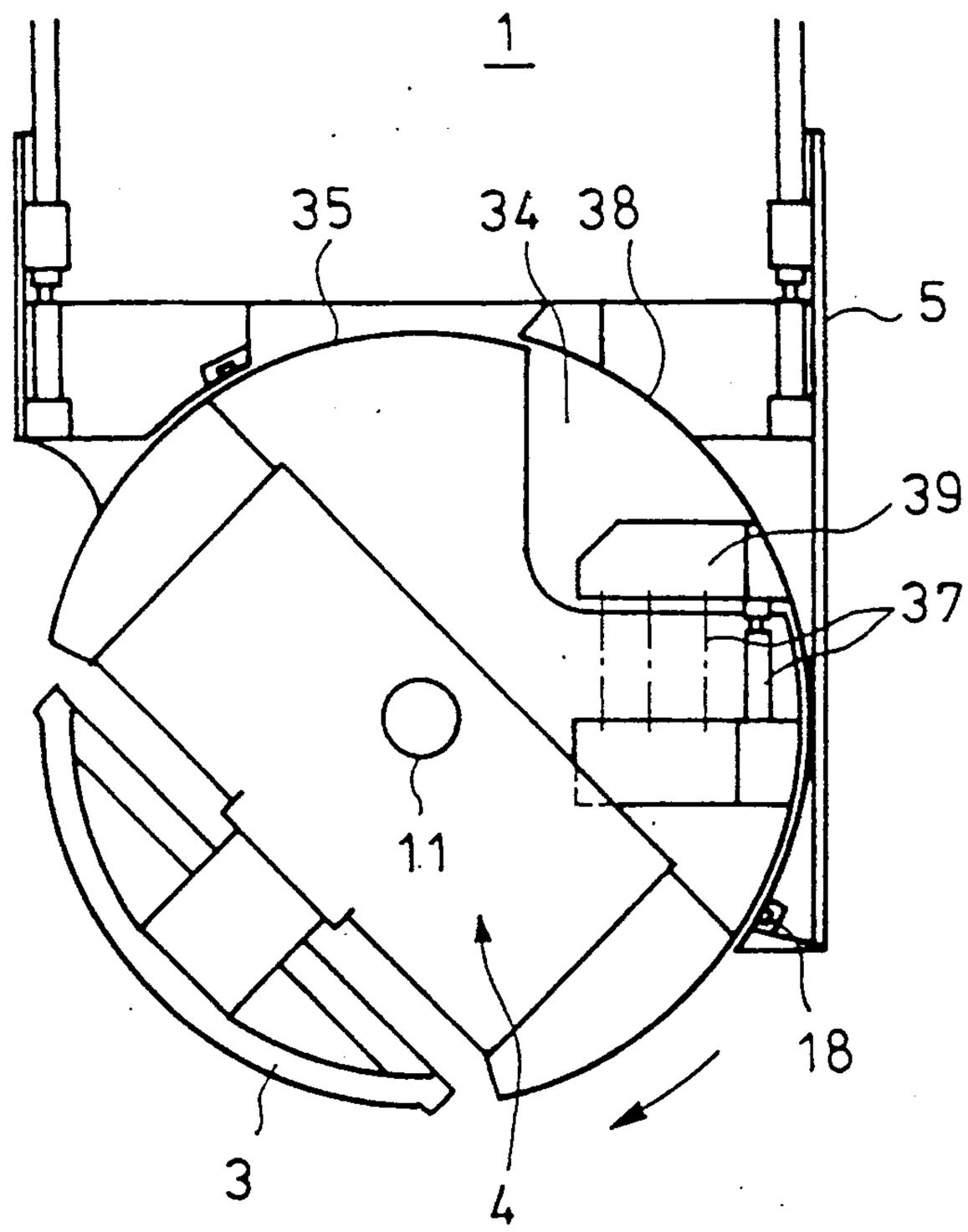

Fig.13

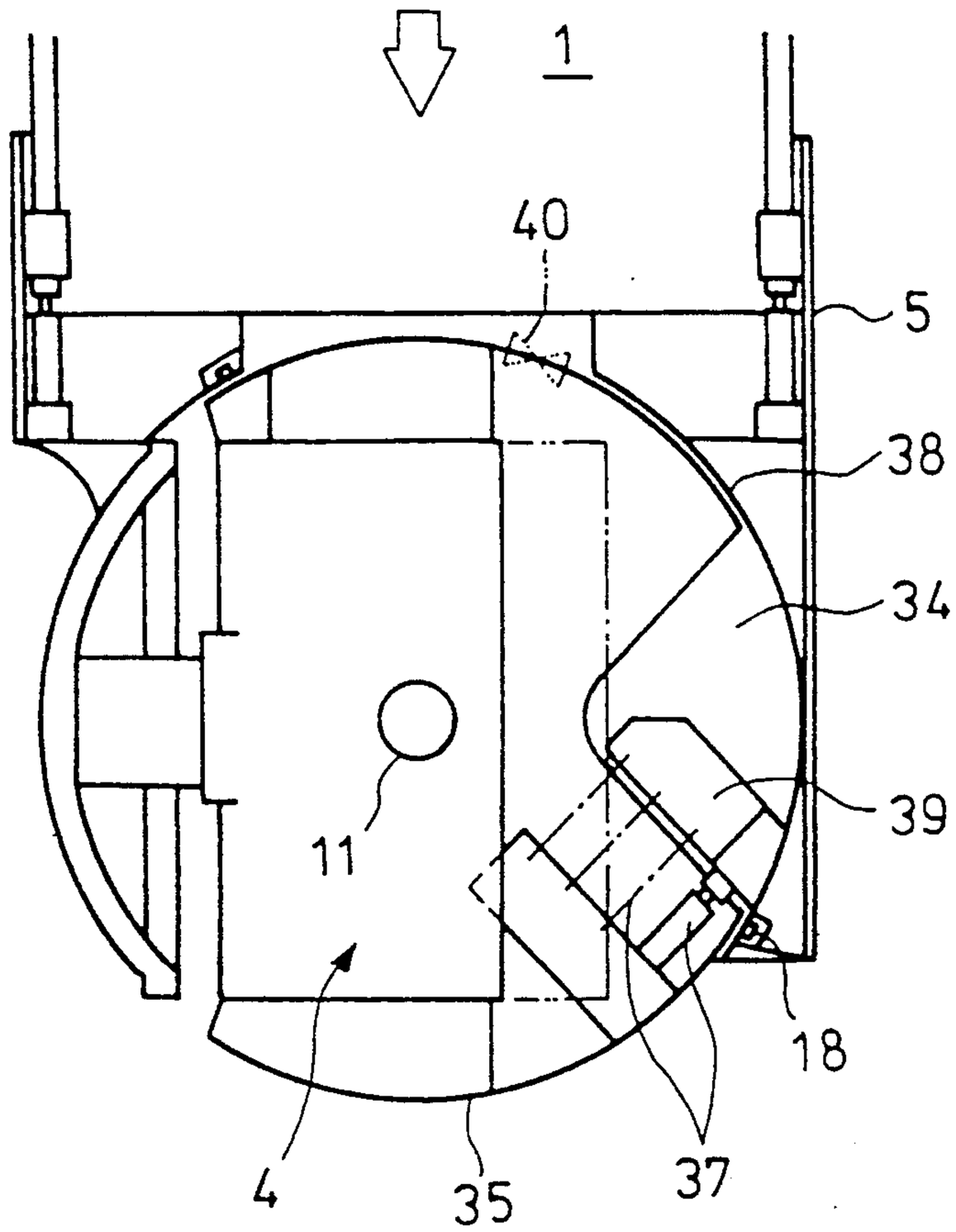

Fig.14

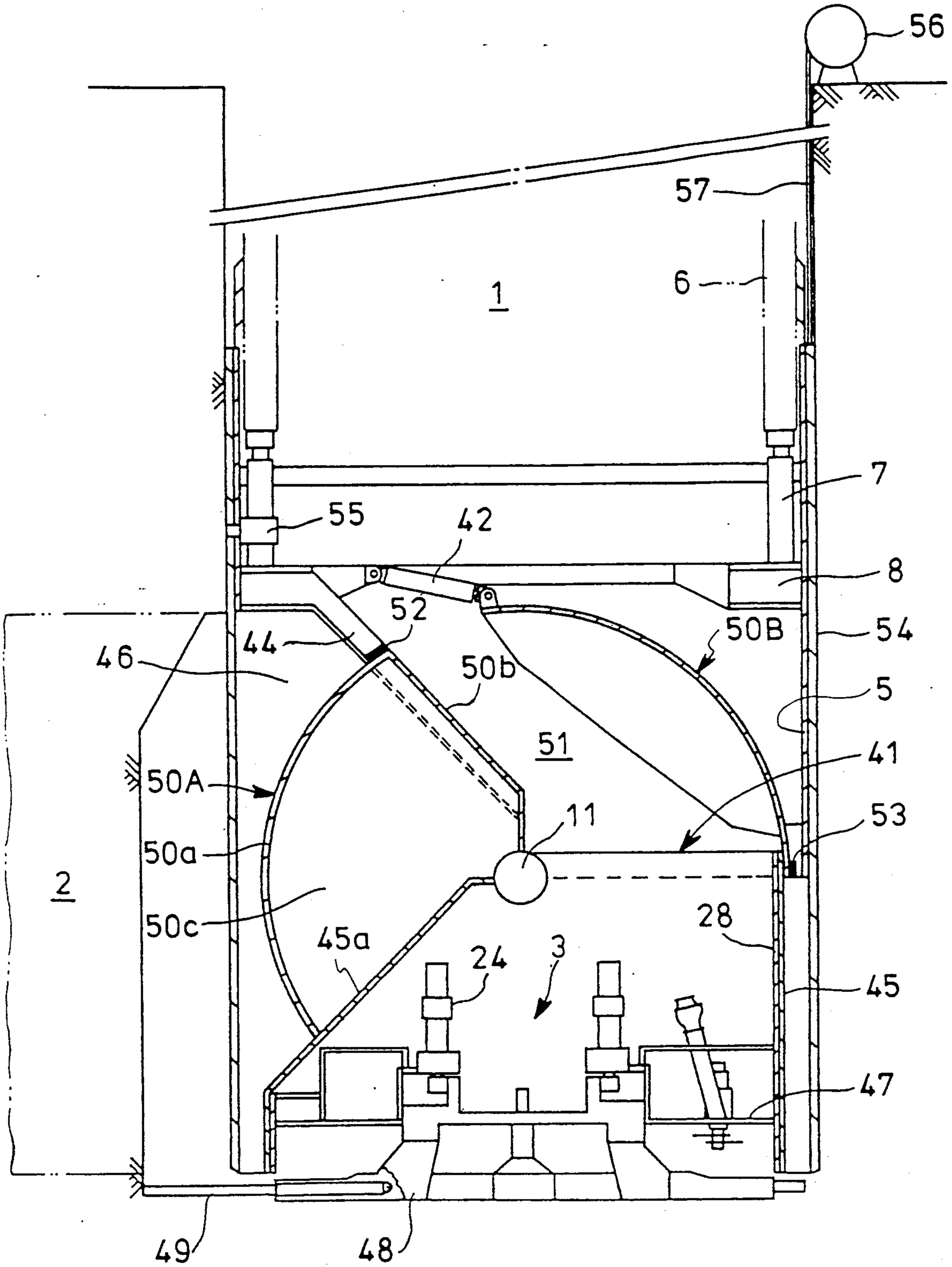
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Fig.15

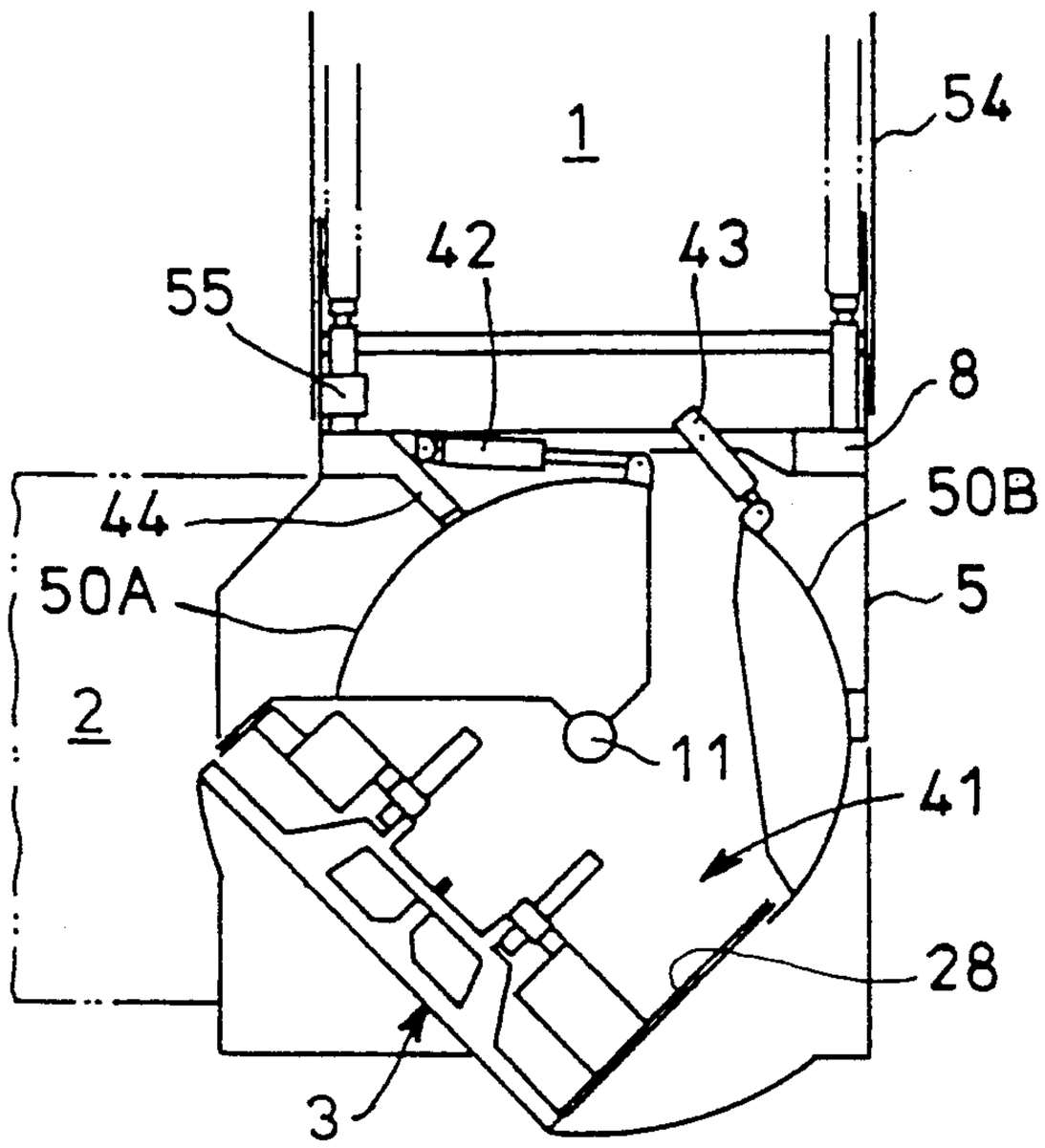
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Fig.16

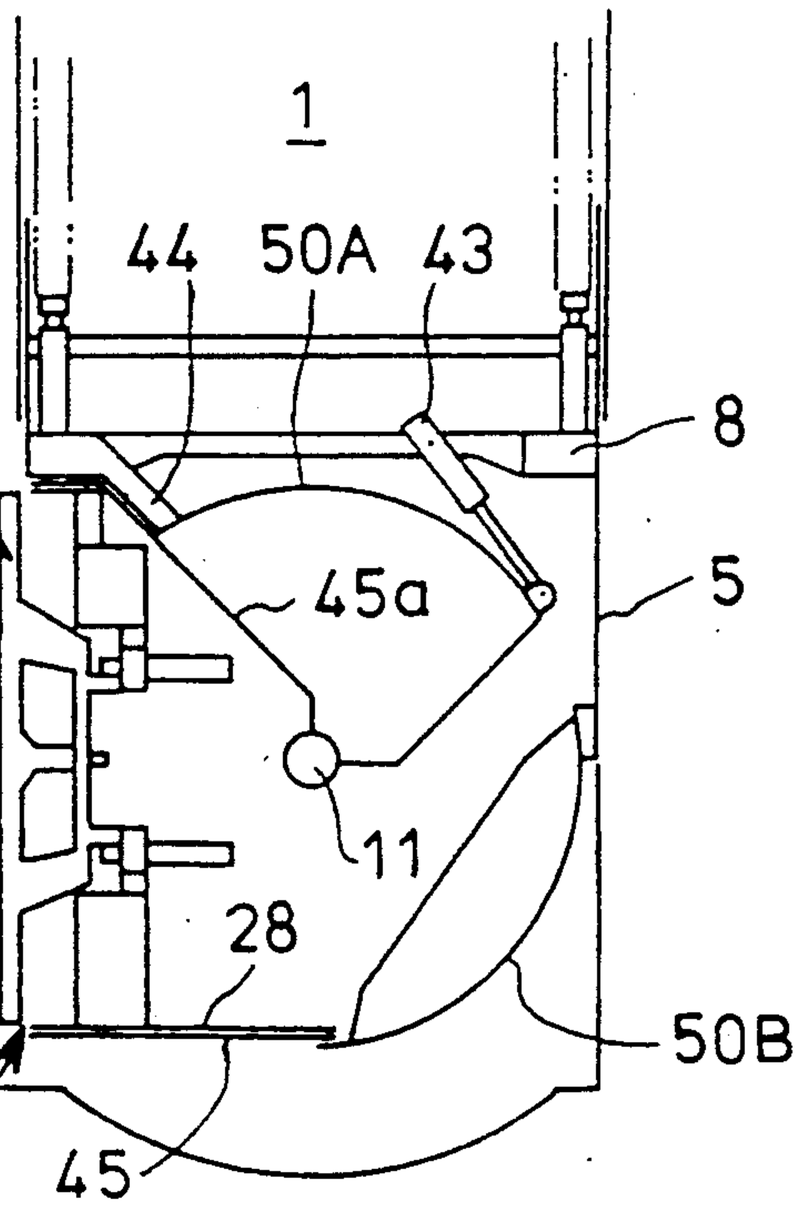
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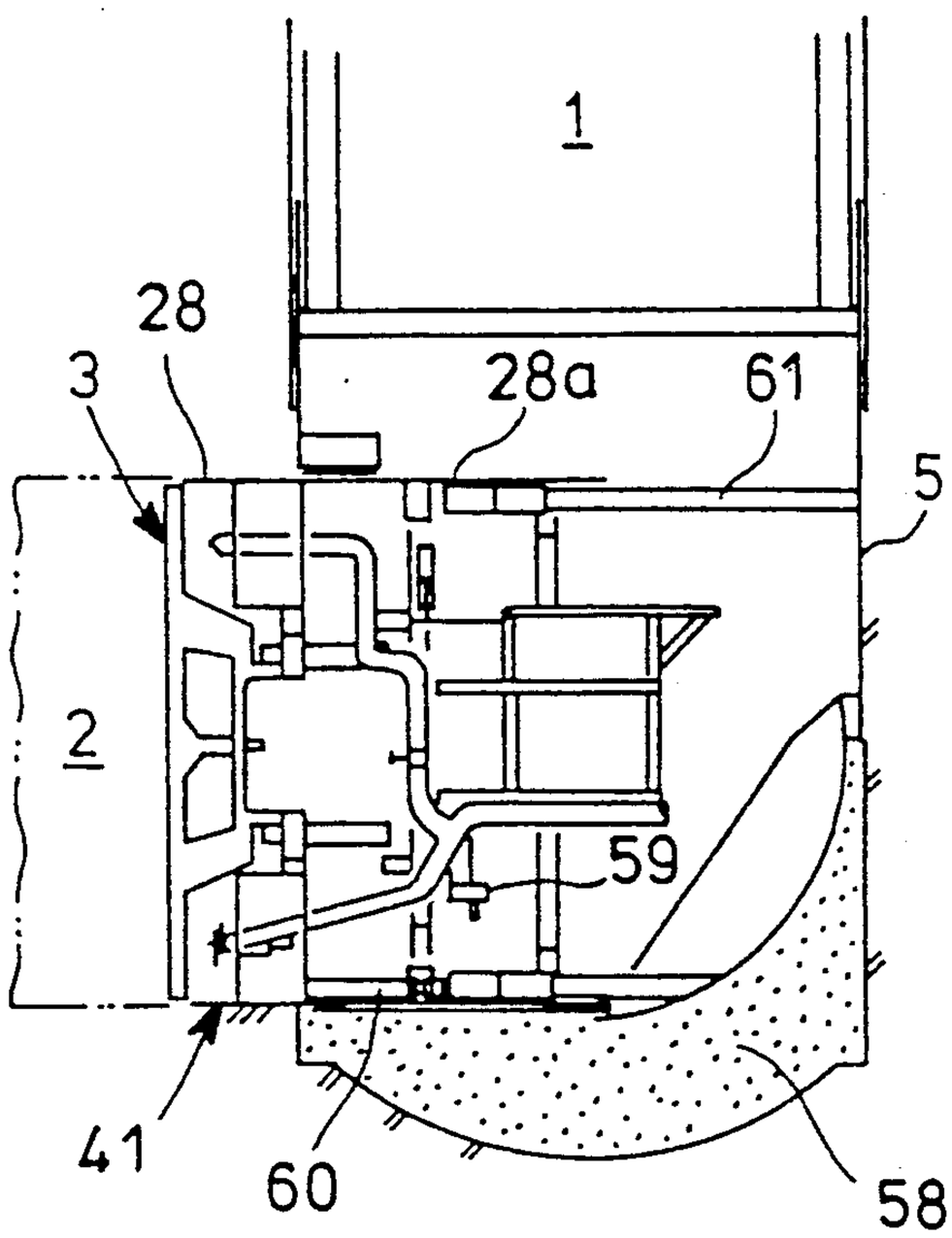
Fig.17



METHOD AND APPARATUS FOR CONTINUOUSLY EXCAVATING SHAFT AND TUNNEL

BACKGROUND OF THE INVENTION

The present invention relates to a method and an apparatus for continuously excavating a shaft and a tunnel.

As shown in FIG. **1**, in conventional excavation of a tunnel, a shaft a is excavated by a drive or caisson method and then a shield excavator b is conveyed into a bottom of the shaft a so as to excavate a tunnel c.

In this conventional system, it is very troublesome to convey the excavator b into the shaft a. A further problem is that separate machines for respectively excavating the shaft a and the tunnel c must be provided, which will disadvantageously increase excavating costs.

In view of these, a primary object of the present invention is to provide a method and an apparatus for continuously excavating a shaft and a tunnel by a single machine.

BRIEF SUMMARY OF THE INVENTION

The present invention is directed to a method for continuously excavating a shaft and a tunnel comprising the steps of excavating the shaft by propelling a shield excavator in unison with a shield frame for excavation of the shaft, said shield frame being swingably and vertically connected to a leading portion of the shield frame, swinging said excavator to a direction of excavating a tunnel, and excavating the tunnel by propelling only said shield excavator. The present invention is also directed to an apparatus for continuously excavating a shaft and a tunnel comprising a skin plate for excavation of the shaft on a shield frame for excavation of the shaft and having descending jacks, a spherical seal body accommodated in a leading portion of said skin plate, supporting pivots on the skin plate for swingably supporting said spherical seal body about a horizontal line perpendicular to an axis of said skin plate, a peripheral seal member in the skin plate so as to contact an outer periphery of said seal body and a shield excavator supported by said seal body through an inner skin plate section.

Therefore, according to the present invention, the downwardly directed shield excavator in the vertical shaft-excavating skin plate excavates the shaft. Then, the spherical seal body is swung about the supporting pivots to cause the excavator to swing into the horizontal posture. Thus, the excavator can continuously excavate the tunnel, too.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view illustrating a conventional system for excavating a tunnel;

FIG. **2** is a side view in section of a first embodiment of the present invention;

FIG. **3** is a front view illustrating swinging state of a shield excavator shown in FIG. **2** with its right half being cut away;

FIG. **4** is a bottom view of FIG. **2**;

FIGS. **5–7** are side views illustrating swinging sequence of the shield excavator and mode of operation of a spherical seal body;

FIGS. **8–10** are side views illustrating a second embodiment of the present invention and mode of operation thereof;

FIGS. **11–13** are side views in section illustrating a third embodiment of the present invention and mode of operation thereof;

FIG. **14** is a side view in section of a fourth embodiment of the present invention; and

FIGS. **15–17** are schematic views illustrating steps of continuously excavating a shaft and a tunnel by the machine shown in FIG. **14**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. **2–4**, a first preferred embodiment of the present invention will be described. A shield excavator **4** is a main body of a system, is provided with cutter means **3** for excavating a shaft **1** and a tunnel **2** and is within a leading portion of a skin plate **5** only for excavation of the shaft **1**. The excavator **4** is housed in a spherical seal body **9** below a shield frame **8** which is for excavation of the shaft **1**, which is integral with the plate **5** and which is provided with descending jacks **7**. The jacks **7** descend with their reaction forces being received by segments **6**. The seal body **9** is sized to be housed within the skin plate **5**.

The seal body **9** vertically movably supports an inner skin plate section **28** through a peripheral seal member **10** at the lower edge of the body **9**. As shown in FIG. **3**, the body **9** has right and left supports **12** which are fitted over supporting pivots **11** extending, from an inner surface of the skin plate **5**, on a horizontal line **13** perpendicular to an axis **5'** of the skin plate **5**, so that the excavator **4** can be caused to swing in unison with the seal body **9** through 90° to the forward direction of excavating the tunnel **2** (or to the direction toward the left in FIG. **2**; hereinafter, the left and right sides of FIG. **2** are respectively referred to as front and rear sides). The seal body **9** is cut off horizontally at its lower portion to expose the cutter **3** and is further cut off at its portion extending immediately above the horizontal line **13** toward the rear side by a length of arc, thereby defining an opening **14**. Thus, front and rear seal sections **15** and **16** are provided.

Part of the front seal section **15** between a horizontal plane including the line **13** and a upper edge of the opening **14** is composed by a plurality of detachably interconnected plate segments **17** which are obtained by cutting the quartered spherical plate through planes including the line **13**.

A peripheral seal member **18** inclined about 45° toward the front side is disposed between the front side of the frame **8** and the rear lower end of the plate **5**, thereby sealing the outer periphery of the seal body **9**.

The shield frame **8** has jacks **19** and **20** for detachably connecting to the plate segments **17** of the front and rear seal sections **15** and **16** respectively to swing the seal body **9** about the pivots **11**.

As shown in FIG. **4**, the cutter means **3** comprises an inner cutter **21** and an outer cutter **23** which is detachably engaged with an outer periphery of the inner cutter **21** by couplings **22** in the cutter **21**. The outer diameter of the outer cutter **21** is made equal to that of the skin plate **5**.

The connecting and disconnecting means **22** are on the inner cutters **21** so that the blocks are selectively moved into and out of the outer cutters **23** for selective

connection and disconnection as shown in FIGS. **2** and **4**.

The cutters **21** and **23** are rotated by a drive **24** on the excavator **4** and are vertically movable by up-down means **25**.

The skin plate **5** has its lower end extending to the outer cutter **23** and has its front end cut off generally in the form of inverted U at **26** for use in excavation of the tunnel **2**. Reference numeral **27** denotes jacks for advancement on the excavator **4** to excavate the tunnel **2**.

In continuously excavating the shaft **1** and the tunnel **2**, as shown in FIG. **2**, the whole system is located or installed such that the excavator **4** is directed downwardly and is swingable to the direction of excavating the tunnel **2**. The cutter means **3** is driven to excavate the shaft **2** while the jacks **7** impart propelling forces to the system until the shaft **1** is excavated to a predetermined depth. Earth and sand dug by excavating the shaft **1** are readily dischargeable through the opening **14** to the ground surface. The dug earth and sand are prevented from intruding into the upper portion of the excavator **4** since the seal body **9** is sealed by the seal member **18** against the skin plate **5** and the shield frame **8**.

After the shaft **1** is excavated to a predetermined depth, continuously the excavation of the tunnel **2** is started. First, the couplings **22** are retracted to separate the outer cutter **23** from the inner cutter **21**. Then, the up-down means **25** are activated to raise the inner cutters **21** into the seal body **9**. The inner cutter **21** is sized to be capable of being housed in a spherical inner surface R of the seal body **9**.

Thereafter, the jacks **19** and **20** are extended to cause the seal body **9** to swing about the line or axis **13** by a length of arc of one plate segment **17** as shown in FIG. **5** and then are disconnected from the associated plate segments **17**. The plate segment **17** disconnected from the jack **19** is also disconnected from the front seal section **15** and is connected to the rear seal section **16** and to the jack **20**. The jack **19** is connected to the succeeding plate segment **17** of the front seal section **15**.

Next the jacks **19** and **20** are again extended to rotate the seal body **9** by the length of arc of one plate segment **17**. As shown in FIG. **6**, such operation is repeated until the excavator **4** is horizontally directed as shown in FIG. **7**.

Then, unnecessary component parts are removed and required component parts are added. Back anchors **29** are attached to the inner surface of the skin plate **5** and the rear seal section **16**. Reaction forces from the jacks **27** are received by back anchors **29** and the tunnel **2** is excavated while sealing is maintained at an inner skin plate section **28**.

In this operation, especially in swinging of the excavator **4**, the latter is completely housed within the inner surface R of the seal body **9** so that swinging of the excavator **4** can be carried out by a relatively little force in a simple manner.

In swinging of the excavator **4**, the plate segments **17** are sequentially disconnected from the front seal section **15** and connected to the rear seal section **16** so that the opening **14** can be always maintained in a large size to assure a sufficient working place. Due to the sealing effect by the body **9** with the seal member **18**, intrusion of dug earth and sand into the upper portion of the skin plate **5** is prevented.

So far it has been described that the disconnectable outer cutter **23** is provided; alternatively, the inner cutter **21** may be provided with an over-cutter which can be extended/retracted.

When a vertically movable sheath pipe **5A** (See FIG. **2**) is provided to surround the skin plate **5**, resistance encountered in excavating the shaft **2** is relieved.

Next a second embodiment of the present invention will be described with reference to FIGS. **8–10**. A inner shell **30** in the form of frustum of a sphere obtained by cutting off upper and lower portions of a sphere above and below the horizontal line **13** is swingable about the line **13** and is disposed to surround the excavator **4**. An outer shell **31** also in the form of a frustum of a sphere has a frustum height greater than that of the inner shell **30** and is fitted over the inner shell **30**. Thus the second embodiment has a double-shell spherical seal body **32**. The outer shell **31** is also swingable about the line **13** along the seal member **18** described above with reference to FIG. **1**. Reference numeral **33** denotes an opening or space **31** above the outer shell **31**.

FIG. **8** illustrates the state that, after the excavation of the shaft **1**, a tunnel is about to be excavated where the excavator **4** is directed completely downwardly and the peripheral seal member **18** is inclined such that the member **18** contacts the front upper and rear lower sides of the outer shell **31**.

First, a jack (not shown) between the outer and inner shells **31** and **30** causes the inner shell **30** to swing as shown in FIG. **9**. Then, a jack (not shown) between the shield frame **8** and the outer shell **31** causes the outer shell **31** to swing as shown in FIG. **10**.

The inner shell **30** is again caused to swing with respect to the outer shell **31** as shown in FIG. **10** in a manner substantially similar to that described above, thereby locating the excavator **4** in a horizontal position or posture. Thus, the swinging operation for the inner and outer shells **30** and **31** is completed.

According to the second embodiment, the excavator **4** is housed within an inner spherical surface R of the inner shell **30**, which facilitates the swinging movement. The swinging movement can be carried out while the opening **33** is always maintained and sealing is always assured between the double shell seal body **32** and the peripheral seal member **18**.

FIGS. **11–13** show a third embodiment of the present invention in which the shield excavator **4** is surrounded wholly by a single spherical seal body **35** except a upper opening **34** and a lower portion of the excavator **4**. The cutter means **3** has an over-cutter **36** retractable within the inner surface R of the seal body **35** and is spherical at its lower surface. Reference numeral **37** represents swing jacks in the seal body **35**; **38**, a guide plate at the rear side of the shield frame **8**; and **39**, reaction-force receiving means.

In the third embodiment, when the excavator **4** in the position shown in FIG. **11** is to be swung, first the over-cutter **36** is retracted and the reaction-force receiving means **39** is attached to the guide plate **38** at the opening **34**. The jacks **37** are extended with the reaction forces being received by the means **39** so that the seal body **35** is caused to swing over a predetermined angle; then, the attached position of the receiving means **39** is displaced as shown in FIG. **12**. Such operation is sequentially carried out until the excavator **4** is located in the horizontal position or posture as shown in FIG. **13**. A working opening **40** as shown in FIG. **13** is opened since the opening **34** is now away from the shield frame **8**.

The third embodiment has also the shield excavator **4** which can be housed within the inner peripheral surface

R of the seal body **35**, which facilitates the swinging movement of the excavator **4**. The swinging movement can be carried out while sealing is always assured between the single seal body **35** and the peripheral seal member **18**.

Next a fourth embodiment of the present invention will be described with reference to FIGS. **14–17**. In the fourth embodiment, a shield excavator **41** having the cutter means **3** for excavating the shaft **1** and the tunnel **2** is a main body of the system. The excavator **41** is suspendedly supported at its upper end by the supporting pivots **11** on a leading end portion of the skin plate **5** which is used only for excavation of a shaft. The leading portion of the skin plate **5** above the pivots **11** is cut off through 45° and a closing plate **44** is disposed thereover; the inner skin plate section **28** which constitutes the excavator **41** is cut off, at its upper portion adjacent to the closing plate **44**, through 45° downwardly starting from the portion adjacent to the pivots **11**; and, the section **28** including such cut-off portion is covered with a cover **45**. Thus, a space **46** for permitting the swinging movement is defined between a cut-off-portion covering portion **45***a* of the cover **45** and the closing plate **44** so that the excavator **41** can be swung in one direction (in the forward direction) by 90° about the pivots **11** by two jacks **42** and **43** (See also FIG. **15**). The cutter means **3** is driven by the drive **24** on a bulk head **47** and is provided with an over-cutter **49** located along the outer periphery of a cutter frame **48**.

Mounted on the the covering portion **45***a* is a spherical seal body **50**A which comprises an arcuate portion **50***a* which has a radius with respect to the axis of the pivots **11** and has one end on the closing portion **45***a* and the other end extending through the closing plate **44**, an end plate **50***b* which connects the other end of the arcuate portion **50***a* with the pivots **11** in coplanar relationship with the plate **44** and side plates **50***c* which close the frame structure constructed by the plates **50***a* and **50***b*. Mounted on the upper end of the excavator **41** is a spherical seal body **50**B whose center is at the intersection of the axis of the inner skin plate section **28** with the axis of the pivots **11** and which is integral with the seal body **50**A. Upon swinging of the excavator **41**, the seal body **50**A is displaced while guided by a through opening of the closing plate **44**. Simultaneously, the seal body **50**B is slidably guided by the inner wall surface of the skin plate **5**. Thus the swinging of the excavator **41** is carried out smoothly and space defined between the seal bodies **50**A and **50**B is used as a passage **51** for communication of the interior of the inner skin plate section **28** with that of the skin plate **5**. Reference numeral **52** is a seal member disposed on the closing plate **44** where the seal body **50**A is extended therethrough, and serves to seal the sliding surface of the seal body **50**A; and **53**, a seal member which is disposed inside of the leading portion of the skin plate **5** and serves to seal the sliding surface of the seal body **50**B.

A sheath pipe **54**, which serves to maintain the straight alignment of the axis of the excavator **41** with that of the skin plate **5**, is disposed to surround the excavator **41** and the outer cylindrical surface of the skin plate **5**. In order to engage and disengage the sheath pipe **54** with and from the skin plate **5**, a hydraulic-jack type knock **55** extendible into and retractable from the sheath pipe **54** through the skin plate **5** is mounted on the inner wall surface of the skin plate **5** as a sheath-pipe engaging and disengaging means. A wire rope **57** is engaged at its lower end with the rear end of the sheath pipe **54** so that the latter, when disengaged from the skin plate **5**, may be lifted to the ground surface by the operation of a winch **56** installed on the ground surface.

Upon continuously excavating a shaft and a tunnel, alignment between the shield excavator **41** and the skin plate **5** is maintained by the sheath pipe **54** and, as shown in FIG. **14**, the whole system is so located or arranged that the excavator **41** is directed downwardly and is swingable to the direction of excavating a tunnel **2**. Excavation of the shaft **1** to a predetermined depth is carried out by driving the cutter means **3** while the thrust forces are imparted by the jacks **7**. In this case, when the excavator **41** approaches the upper level of the tunnel **2** to be excavated, the over-cutters **49** positioned in the direction of swing of the excavator **41** are extended radially outwardly from the outer periphery of the cutter frame **48**, thereby excavating the natural ground on one side of the seal body **50***a* to provide a space through which the excavator **41** can be swung. Earth and sand dug in excavating the shaft **1** are readily discharged to the ground surface since the interior of the inner skin plate section **28** is communicated with that of the skin plate **5** through the passage **51** defined by the seal bodies **50**A and **50**B. Even when any dug earth and sand happen to enter from the space between the pipe **54** and the inner skin plate section **28** into the sheath pipe **54**, they cannot intrude into the plate section **28** and the skin plate **5** since the plate section **28** is covered with the cover **45**, the skin plate **5** is closed by the closing plate **44** and the seal members **52** and **53** are disposed on the sliding portions of the seal bodies **50**A and **50**B.

Thereafter, in order to begin to excavate the tunnel **2**, the knock **55** is retracted to disengage the sheath pipe **54** from the skin plate **5**. A plurality of winches **56** installed on the ground surface are energized to wind the wire ropes **57** which are securely fixed to the sheath pipe **54**, thereby lifting the latter simultaneously with retraction of the over-cutter **49** which has been extended. Then the cutter means **3** is driven to dig the natural ground in front of the cutter means **3** while the jack **42** connecting the shield frame **8** with the seal body **50**A is extended to swing the excavator **41**. In this case, it is impossible to swing the excavator **41** through 90° only one jack **42**; therefore, as shown in FIG. **15**, additional jack **43** is used and the operation of the jacks **43** and **42** are alternately switched to swing the excavator **41** through 90° in the direction of the tunnel **2** to be excavated as shown in FIG. **16**. The excavator **41** is smoothly swung since the seal body **50**A is guided by the through opening of the cover plate **44** and the outer surface of the seal body **50**B is guided by the inner surface of the skin plate **5**.

Upon completion of the swinging movement of the excavator **41**, a hole is made through, for instance, the seal body **50**B and a back fill material **58** is injected through this hole to solidify or improve the ground below the excavator **4** as shown in FIG. **17**. The shield jacks **42** and **43**, the seal body **50**A, the supporting pivots **11**, the cut-off portion closing portion **45***a* and so on are removed and additional inner skin plate member **28***a* is joined to the rear end of the inner skin plate section **28** to prolong the latter in the form of pipe. Within the prolonged cylindrical inner skin plate section **28**, various equipments are disposed such as an elector **59**, a shield jack **60** and so on required for carrying out a shield method. In order to receive the reaction force of the advancing shield jack **60**, a back anchor **61** is installed. Under these conditions, the excavator **41** is

activated again to excavate the tunnel **2** by a conventional shield method.

Thus, by using only one shield excavator **41**, the shaft **1** and the tunnel **2** can be continuously excavated.

It is to be understood that the present invention is not limited to the above-described embodiments and that various modifications may be made without leaving the true spirit of the present invention. For instance, the sheath pipe **54** may be used in the embodiments described above with reference to FIGS. **2** to **13**. The swinging movement of the excavator **4** or **41** may be carried out by any suitable means instead of the swinging jacks. The dug materials may be discharged to the ground surface by a liquid transportation system or a conveyer system. In order to engage and disengage the sheath pipe **54** with and from the skin plate **5**, any suitable means may be employed instead of the hydraulic-jack type knock **55**.

As described above, according to the present invention, the shield excavator is swingably connected to the leading portion of the shaft-excavating shield frame so that after the shaft is excavated to a predetermine depth, the shield excavator is caused to swing to change its posture to continuously excavate a tunnel. As a result, unlike the conventional system for excavating a shaft and a tunnel, the step for conveying a shield excavator into the bottom of the shaft can be eliminated and it is not needed to provide a shield excavator for excavating a shaft and another shield excavator for excavating a tunnel independently with each other. Thus, from the standpoint of operation and expense, the present invention is much advantageous over the prior art.

When the shield excavator is so designed and constructed to be housed in a spherical seal body which in turn is disposed in the leading portion of the skin plate, the shield excavator can be caused to swing readily and with little forces without any adverse effects.

What is claimed is:

1. A method for continuously excavating a shaft and a tunnel comprising the steps of excavating the shaft by propelling a shield excavator in unison with a shield frame for excavation of the shaft, said shield excavator being swingably and vertically supported by a spherical seal body accommodated in a leading portion of the shield frame, swinging said shield excavator to a direction of excavating a tunnel while sealability is retained by said spherical seal body, and excavating the tunnel by propelling only said shield excavator.

2. An apparatus for continuously excavating a shaft and a tunnel comprising a skin plate for excavation of the shaft on a shield frame and said shield frame having descending jacks for imparting propelling forces, a spherical seal body accommodated in a leading portion of said skin plate, supporting pivots on the skin plate for swingably supporting said spherical seal body about a horizontal line perpendicular to an axis of said skin plate, a peripheral seal member in the skin plate so as to contact an outer periphery of said seal body and a shield excavator supported by said seal body through an inner skin plate section.

3. The apparatus according to claim **2** further comprising a sheath pipe vertically displaceable along the outer periphery of the skin plate and connectable to said skin plate.

4. The apparatus according to claim **2** wherein said shield excavator is houseable in a spherical surface of the spherical seal body in the skin plate.

5. The apparatus according to claim **2** wherein said spherical seal body comprises mutually detachable plate segments which are obtained by cutting a quartered sphere along planes including an axis of said pivots.

6. The apparatus according to claim **2** wherein said spherical seal body is of double shell type comprising an inner shell for accommodating the shield excavator and an outer shell swingable along said seal member and also swingable with respect to said inner shell.

7. The apparatus according to claim **2** wherein said spherical seal body is a single structure.

8. The apparatus according to claim **2** wherein said seal body is caused to swing by means of jacks.

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